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A comparative assessment of contaminants in fish from four resacas of the Texas, USA–Tamaulipas, Mexico border region

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Abstract

A recent survey of contaminant information for the Lower Rio Grande Valley (LRGV), Texas, has shown that little is known about contaminants and their impacts on biota of resacas (oxbows) along the US–Mexico border. In 1996, fish were collected from four resacas in the Texas–Tamaulipas border region to assess contaminant loadings and their impacts on fish and birds. Tissue residue concentrations in fish were analyzed and also compared to two histopathological bioindicators of unhealthy environmental conditions. Of the organochlorine insecticides measured, DDE was the most common and was present at relatively high concentrations (10 μg/g w/w) at some sites. DDE concentrations were nearly 20 times greater in fish from resacas in Texas than from resacas in Tamaulipas, although the limited sample sizes obtained precluded statistical comparisons. DDE concentrations in fish from the two Texas resacas were also greater than those reported in fish from nearby areas during the 1980s and 1990s. Most trace element concentrations were similar among resacas from Texas and Tamaulipas. Arsenic, however, was two to six times greater in fish from a downtown resaca in Matamoros than in fish from other resacas in Tamaulipas and Texas. The bioindicators, pigment accumulation, and macrophage aggregates (MAs), in general, reflected the contamination indicated by the tissue residues for each site. Overall, it appears that some resacas of the US–Mexico border region are contaminant sinks and could pose potential health or reproductive problems for fish and wildlife, and humans that consume fish from those sites. Published by Elsevier Science Ltd.

Keywords: Fish; Contaminants; DDE; Metals; US-Mexico border

1. Introduction

The human population in cities along the US–Mexico border has grown to nearly 10 million in the 1990s (Border Pact Report, http://borderpact.org). This population growth has been linked to the growth of textile and apparel industries. Currently, over 3200 maquiladoras (assembly plants) are established along the US–Mexico border (SECOFI 1999, http://200.38.187.204/bis). A continuous rise in the human population along with an increase in the maquiladora industry has resulted in increased concern about contaminants and their impacts on wildlife and human health along the US–Mexico border.

The Lower Rio Grande Valley (LRGV) extends from Starr to Cameron counties in Texas, USA, and from Ciudad Miguel Aleman to the Gulf of Mexico in Tamaulipas, Mexico. In the LRGV, agriculture is an additional source of contaminants. The LRGV has a combined crop and citrus area of about 810, 000 ha (Texas Water Resources Institute, 1994). The main crops are cotton, vegetables, and sugar cane. Herbicides comprise about 60%, and insecticides about 20%, of the total pesticides used on LRGV crops (Gianessi and Anderson, 1995). Organophosphorous (>60%) and carbamates (about 25%) are the most extensively used insecticides, and only about 1.5% are organochlorines (Gianessi and Anderson, 1995).

Oxbow lakes, which are commonly known as resacas in the LRGV, are widely used by wildlife in the region (Jahrsdoerfer and Leslie, 1988). Resacas used to be periodically flooded by Rio Grande waters but because of changes in river hydrology and flow today, most are completely separated and

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Table 1
List of US–Mexico border resacas and morphometric values for fish species collected

Resaca	State, country	Species	Number of fish in pooled sample	Weight[a] (g)	Length[a] (mm)	Moisture[a] (%)	Lipid[a] (%)
El Laguito	Tamaulipas, Mexico	blue tilapia	5	156	212	76.7	12.1
		Rio Grande cichlid	1	35	122	72.1	20.5
Las Rusias	Tamaulipas, Mexico	white crappie	3	87	192	72.1	20.0
		freshwater drum	1	143	233	72.8	16.2
		gizzard shad	5	136.4	240	70.0	18.9
La Coma	Texas, USA	smallmouth buffalo	2	1415	455	71.2	14.9
		common carp	2	453	330	75.3	20.2
Los Fresnos	Texas, USA	white crappie	2	140	225	70.5	14.6
		gizzard shad	5	293	310	70.5	16.9
		longnose gar	1	1380	680	61.6	19.1

[a] Arithmetic means.

receive water almost exclusively from runoff and rainfall (Texas General Land Office, 1995). Their proximity to agricultural areas and urban environments raise concerns that resacas may act as contaminant sinks and could potentially affect the wildlife that use them. There have been few attempts to investigate or compare the status of contaminants in fish and wildlife of LRGV resacas (Wainwright, 1998; Mora and Wainwright, 1998). Our study had the following objectives: (1) to assess contaminant loadings and their effects on fish from resacas located within agricultural and urban areas in the LRGV, Texas, through tissue analysis and histopathology, (2) to compare concentrations of contaminants in fish from resacas between Texas, USA, and Tamaulipas, Mexico, and (3) to investigate possible causes for observed effects on fish-eating birds feeding in resacas.

2. Materials and methods

Fish were collected during October 1996 from four resacas, two on each side of the Texas–Tamaulipas border. Monofilament gill nets measuring 125 ft in length by 8 ft deep were used to collect the fish. Resacas used for collection in Texas included La Coma (Hidalgo County) and Los Fresnos (Cameron County). Resacas used for collection in Tamaulipas included El Laguito, in downtown Matamoros, and Las Rusias, northwest of the City of Matamoros. In the US, common carp (*Cyprinus carpio*) and smallmouth buffalo (*Ictiobus bubalus*) were collected at the La Coma site; and white crappie (*Pomoxis* spp.), gizzard shad (*Dorosoma cepedianum*), and longnose gar (*Lepisosteus osseus*) at the Los Fresnos site. In Mexico, blue tilapia (*Oreochromis aurea*) and Rio Grande cichlids (*Cichlasoma cyanoguttatum*) were collected at El Laguito; and white crappie, freshwater drum (*Aplodinotus grunniens*), and gizzard shad, at Las Rusias in Matamoros (Table 1). Fish samples were processed according to TNRCC procedures (1999).

Tissue analysis involved removing the stomach contents from all fish before grinding and homogenization with a meat grinder and blender. One composite sample of each fish species collected at each site was analyzed for trace elements and chlorinated hydrocarbons at the analytical facility of the Texas Parks and Wildlife Department, San Marcos, TX. Organochlorines were analyzed by GC-MS following EPA method 608. The method reporting limits were 0.025 μg/g w/w for chlorinated pesticides and 0.050 μg/g for PCBs. Arsenic, lead, and selenium were analyzed in fish tissue by EPA method 200.9, and mercury by EPA method 245.6 (US Environmental Protection Agency, 1991). Metal extracts were analyzed with a Varian Spectra AA model 640Z, with graphite furnace and Zeeman background corrections. Mercury samples were analyzed by cold vapor atomic absorption and a thermoseparation mercury monitor model 3200, with stannous chloride as the reducing agent. Detection limits ranged from 0.020 μg/g w/w for Hg to 0.25 μg/g w/w for As. Variation between duplicates was within ±15%, recoveries for chlorinated pesticides averaged 70% and for trace elements 106%.

A total of 18 additional fish were collected from the four sites for qualitative gonad and liver histopathology. Samples were preserved in NOTOX and subsequently processed and embedded in paraffin and sectioned at 6 μm. Sections were stained with hemotoxylin and eosin to observe incidence of macrophage aggregates (MAs), or

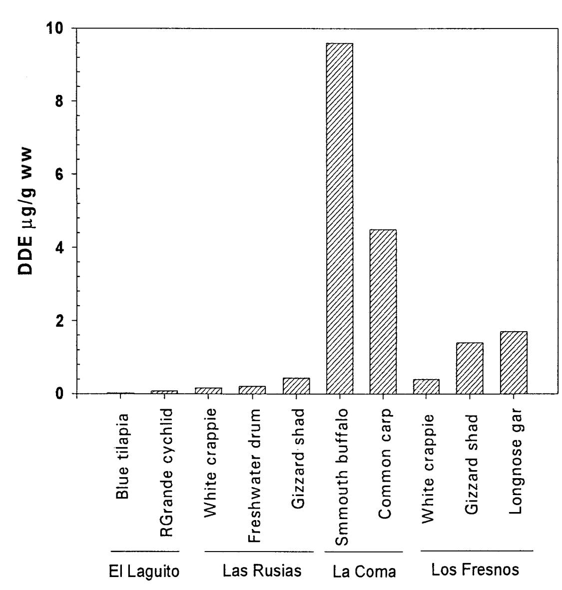

Fig. 1. DDE in fish from four resacas of the US–Mexico border.

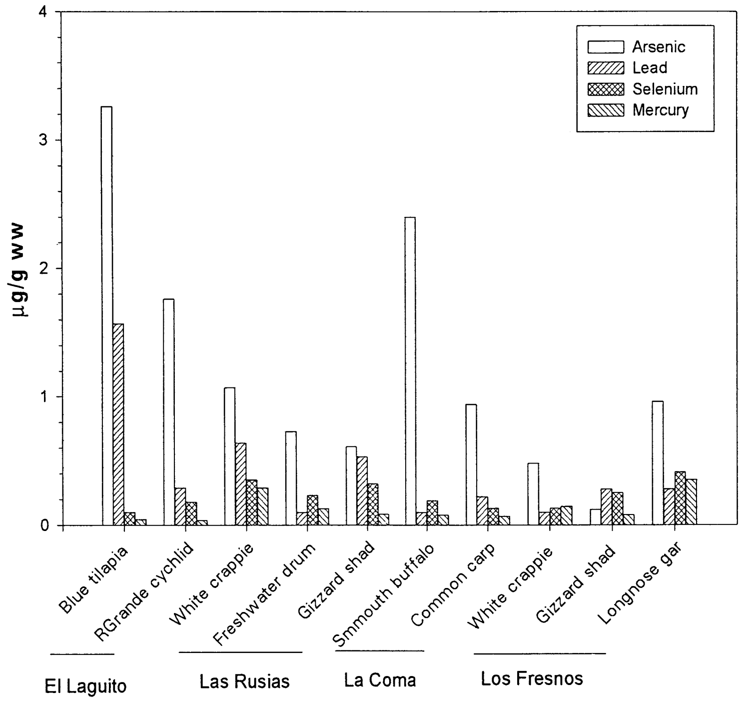

Fig. 2. Trace elements in fish from four resacas of the US–Mexico border.

Ziehl–Nielsen acid fast stain, or Prussian blue to evaluate occurrence of lipofuschin/ceroid and hemosiderin, respectively (Lillie, 1965; Luna, 1968).

Due to differences in the species available from the different resacas and the limited number of pooled samples analyzed, only a few statistical comparisons were possible. Linear regression analysis was used to determine if concentrations of DDE were correlated with fish weight or length with $P \leq .05$ considered significant.

3. Results and discussion

The main organochlorine detected in the pooled fish samples was p,p'-DDE (a metabolite of DDT; Fig. 1). Other chlorinated hydrocarbons were detected at very low levels in only a few samples. DDE ranged from below detection limits to 9.6 μg/g w/w (Fig. 1). The highest concentration was detected in smallmouth buffalo from Resaca de la Coma. On average, DDE concentrations were 20 times higher in fish from the two resacas (La Coma, Los Fresnos) in the US, than in fish from the two resacas (El Laguito, Las Rusias) in Mexico (Fig. 1).

Two fish species, smallmouth buffalo and carp, were collected only at one Resaca (La Coma) in the US. These two fish species had the highest DDE concentrations of all fish collected. These fish were also larger than all other fish species collected. However, linear regression analysis showed no significant correlations between DDE concentrations and fish weight or length (r^2=.55 and r^2=.24, respectively, $P > .05$). This implies that differences in DDE concentrations among fishes were due to differences in sampling locations or species differences such as feeding habits, rather than size.

Comparisons of DDE concentrations within the same species on both sides of the border provided similar, but less substantive results. DDE concentrations in white crappie from the US were 2.5 times greater than in those from Mexico. Similarly, DDE concentrations in gizzard shad were 3.3 times greater in resacas from the US than in those from Mexico. Additionally, DDE concentrations in fish from the two resacas sampled in the US were three times to three orders of magnitude greater than those reported in fish sampled from nearby stations along the Rio Grande as part of the binational toxic contaminants studies in 1993, 1994, and 1995 (TNRCC, 1994, 1997; Davis, Kleinsasser, and Cantu, 1995). DDE concentrations in fish from the two US resacas were also greater than most values reported for fish collected during the late 1980s and early 1990s at nearby sites, such as Donna Reservoir, Llano Grande Lake, and Mercedes Settling Basin (White, Mitchell, Kennedy, Krynitsky, and Ribick, 1983, Texas Department of Health, 1995). The highest historical concentrations of DDE in fish (31.5 μg/g w/w) in the LRGV were reported during the late 1970s in fish collected in Llano Grande Lake just a few miles north of Resaca de la Coma (White et al., 1983). Other recent studies of contaminants in fish from resacas provided similar results to our data (Wainwright, 1998). Mean DDE concentrations in male carp from four resacas near La Coma and Los Fresnos ranged from 0.067 μg/g w/w for Pintail Lake to 1.08 μg/g w/w in the JAS Farms site near La Coma (Wainwright, 1998).

Table 2
Relative concentrations of MAs and pigments

Site	Species	*n*	MAs	Ceroid/lipofuschin	Hemosiderin
El Laguito	blue tilapia	4	none	high (100%)	low (25%)
Las Rusias	gizzard shad	2	low (50%)	low (100%)	low (100%)
Los Fresnos	gizzard shad	5	high (40%)	moderate (100%)	low (40%)
	blue gill	1	low (100%)	low (100%)	none
La Coma	gizzard shad	4	moderate (100%)	moderate (100%)	low (50%)
	smallmouth buffalo	2	none	low (50%)	none

Numbers in parenthesis are the percent of individuals with these symptoms.

Four of five pooled fish samples from US resacas had DDE levels above 1 μg/g, whereas none of the fish collected from resacas in Mexico reached such levels. Some fish-eating birds such as the brown pelican (*Pelecanus occidentalis*) are very sensitive to DDE, and even levels lower than 1 μg/g in the diet could result in critical eggshell thinning (Blus, Neely, Lamont, and Mulhern, 1977). The differences in DDE concentrations in fish between resacas in the US and Mexico could be explained by proximity to agriculture and heavy DDT use in the past. The two resacas in the US are located within agricultural fields, therefore, they could be potential sinks of DDE/DDT from heavy historical use. The resacas in Matamoros, Mexico, were closer to the city or in the city itself, further from agricultural runoff. The relatively high DDE residues in fish from US resacas observed in this study contrast with previous reports of decreasing levels of DDE in most wildlife species in the LRGV (Mora and Wainwright, 1998).

PCBs in fish from our study were all below detection levels, in agreement with most previous and recent studies in the LRGV. For example, in the second phase of the binational study, PCBs (Aroclor 1260) were detected in fish from the Rio Grande at low levels (0.18 μg/g w/w; TNRCC, 1997).

Metal and metalloid concentrations were not significantly different among resacas or among fish species from the US and Mexico (Fig. 2). Arsenic and lead, however, were 1.5 and 6 times higher in fish from resaca El Laguito, downtown Matamoros, than in fish from other resacas in Tamaulipas and Texas. Resaca El Laguito received wastewater from a nearby hospital in previous years (J. Gonzalez, personal communication); thus, it is possible that the higher levels of As in fish from El Laguito could have come from this source. Higher Pb residues in the downtown Matamoros resaca may be explained by increased traffic and exposure to automobile exhaust compared to the other sites.

Selenium and mercury concentrations were low and similar among fish from the four resacas (Fig. 2). Concentrations of Se, Hg, and Pb in fish from US–Mexico border resacas were similar to those found in fish from nearby areas in 1993, 1994, and 1995 (TNRCC, 1994, 1997; Davis et al., 1995). Selenium and mercury levels in fish from our study were also similar to those from fish collected during mid-1980s and earlier 1990s at nearby sites (Walsh, Berger, and Bean, 1977, Texas Department of Health, 1995). Arsenic concentrations, however, particularly in fish from Mexico, were over five times greater than those detected in fish collected in nearby locations in the Rio Grande in previous years. High levels of As also were reported in fish from the Brownsville area in 1984–1985 (Schmitt and Brumbaugh, 1990). It appears that fish collected from resacas or reservoirs not linked directly with the Rio Grande had higher concentrations of trace elements than fish collected directly from the river or its tributaries. This supports the idea that resacas are serving more as contaminant sinks than the Rio Grande. Consequently, greater accumulation of contaminants in biota from resacas than in biota from the Rio Grande should be expected.

Eisler (1987) recommended that for the protection of fish-eating birds, Hg should not exceed 0.1 μg/g w/w in their diet. In this study, four pooled samples (two from each side of the border) had Hg residues above the protection level. Lemly (1996) suggested an Se level of about 0.75 μg/g w/w as the threshold concentration in aquatic food chain organisms for the protection of fish and wildlife that consume such organisms. In our study, all Se concentrations were below this threshold. For the protection of human health, it is recommended that As should not exceed 0.5 μg/g w/w in edible meat products (Jelinek and Corneliussen, 1977). In our study, 80% of the samples exceeded this level, particularly all the fish from Mexico and three of five pooled samples from the US; however, these values were for whole fish.

A total of 18 fish were examined for deposition of the pigments lipofuschin, ceroid, and hemosiderin and for the presence of MAs in liver and gonad (Table 2). One or more of the pigments was detected either in MAs or dispersed in gonadal stroma or liver hepatocytes from fish at all four sites. Tissues from El Laguito blue tilapia had the highest concentrations of pigments relative to the other sites. Pigment was in large masses near acinar pancreatic cells at the margins of the blood vessels but not in MAs. Gizzard shad from Las Rusias had the lowest amount of pigment and only one individual with a few MAs. MAs were most numerous in shad from Los Fresnos and La Coma. Fish from these sites also had moderate concentrations of pigment.

Pigmentation of tissues can result from a number of causes such as stress, poor nutrition, or exposure to toxic chemicals (Blazer, Wolke, Brown, and Powell, 1987). The pigment itself does not usually damage the tissue, but rather is an indicator of the health of the organism or its exposure to a toxic compound. Hemosiderin and lipofuschin/ceroid are yellow-brown granular pigments, which have been observed in tissues of fishes exposed to chemical contaminants (Wolke, 1992). Hemosiderin is a byproduct of hemoglobin breakdown. Lipofuschin and ceroid are both considered lipopigments produced by the peroxidation of unsaturated fatty acids. Histochemical stains used in light microscopy cannot differentiate between the two, but electron microscopy has shown that what differentiates them is probably the source of the lipid (Wolke, 1992). These pigments can be found dispersed in tissues or within MAs. MAs function in fish to protect the body by: (1) recycling iron, (2) storing, destroying, or detoxifying effete material, and (3) their role in the immune response (Agius, 1985). Macrophages and pigments have been suggested as possible bioindicators of environmental chemical exposure (Wolke, 1992). However, because pigments and MAs may be influenced by age, diet, and temperature, among others, cause and effect relationships between their presence and environmental chemical exposure may be difficult to assess.

Our histopathology results compare favorably with the results from the tissue residue analysis. Las Rusias resaca in Mexico was the cleanest of the sites we sampled in terms of the compounds for which we tested and similarly had the lowest concentrations and incidence of pigments and MAs. Conversely, fish from La Coma, Los Fresnos, and El Laguito had elevated levels of contaminants and moderate to high biomarker levels. Low sample sizes make it difficult to draw conclusions about the specificity of the biomarkers to the contaminants we measured. Species differences also make comparisons difficult. Gizzard shad was the most common species in our samples and was taken at three of four sites. Compared to the other species taken, shad are typically less tolerant of stressful conditions while smallmouth buffalo and tilapia are quite tolerant. Biomarker levels in shad reflect the relative contamination among the sites. However, smallmouth buffalo from La Coma, one of the more contaminated sites, showed very little biomarker response.

Overall, it appears that there are still some resacas along the US–Mexico border region that could be categorized as contaminant sinks and could potentially affect wildlife using them. In addition, high concentrations of DDE persist at some hot spots in the LRGV. Contaminant monitoring efforts should continue along the US–Mexico border so that management actions can be taken for the protection of environmental and human health.

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